with the kind regards
of the author

THE PAST AND FUTURE

11.

OF

GEOLOGY

AN INAUGURAL LECTURE

GIVEN BY

JOSEPH PRESTWICH, M.A., F.R.S., F.G.S., &c.

Professor of Geology in the University of Oxford

ON

JANUARY 29, 1875

London
MACMILLAN AND CO.
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PAST AND FUTURE OF GEOLOGY.

I CANNOT enter upon the subject of this address without a brief tribute to the memory of my distinguished and lamented predecessor, Professor Phillips. Educated in geology by his uncle, William Smith, the father of English geology, John Phillips was thus nearly connected with the early history of our science, and lived to give active and efficient aid to its progress during more than half a century. His early training was amongst the Oolitic hills of Gloucestershire and the Midland Counties, but his first independent work was among the Palæozoic rocks of Yorkshire. In later life he returned to the ground of his youth, and spent his last years in investigating the rich and varied succession of life in the different divisions of that Oolitic series, of which his uncle was the first to establish the stratigraphical order; and his "Geology of the

Valley of the Thames" contains the best summary we possess of the geology and palæontology of these strata in this and the adjacent counties.

Besides his chief and early work on the "Geology of Yorkshire," Phillips was also the author of an excellent "Treatise on Geology," of works on the Malvern Hills and on Vesuvius, of several memoirs in the Geological Survey, and of above seventy papers scattered through various scientific periodicals. He was a Fellow of most of our great scientific societies, and the record of his many valuable contributions in each special branch is to be found in their respective proceedings. I have to note his work here.

Shortly after Phillips's arrival in Oxford, the valuable geological collections, many of which had remained hidden for want of space, were transferred from their old quarters to the new and beautiful Museum Oxford now possesses. Valuable as these collections were in particular sections, especially in cave remains, there was very much to be done in completing the series of the local formations, and in the general selection, order, and grouping of the specimens. All this was admirably carried out by Phillips, and the geology of the surrounding district is now illustrated by a suite of fossils amassed and arranged with great judgment, and forming one of the most complete local

series in the kingdom. To Phillips especially is this Museum indebted for the remarkable collection of the remains of the Ceteosaurus of the Great Oolite,—an extinct gigantic reptile the size of a whale and with the gait and amphibious habits of a crocodile. He also brought his great local knowledge of Great Britain to bear on one of the proposed additions to the new Museum, viz. that of the British ornamental rocks, of which the 125 graceful columns which decorate the building each constitutes a specimen; the size and position of the shafts exhibiting to great effect, and with permanent advantage, the character and beauty of the several rocks, including numerous varieties of our Granites, Serpentines, and Mountain Limestones, with some from the more recent Permian, Oolitic, and Purbeck strata. No such collection exists elsewhere, and with it will always be associated the name of the eminent man who by his taste and ability so ably contributed to the success of the work.

But Phillips was not only a geologist; he was a man of great and varied acquirements,—a meteorologist, a botanist, an astronomer, and a physicist. Further, he was a man whose amiable disposition, engaging manners, and eloquent and fluent address, made him beloved as much as he was esteemed; and while his loss to science will be long felt, his mark must remain and his memory will ever be honoured.

When in 1819 Dr. Buckland, who had a few years previously succeeded Dr. Kidd as Professor of Mineralogy, received his appointment to the then recently created Chair of Geology, he spoke of these subjects as the "new and curious sciences of geology and mineralogy." Geology was only then beginning to assume a recognised position, and was passing from purely speculative "Theories of the Earth" to the more philosophical investigations of its structure and organisms. Hutton had sought in natural existing agencies the causes of past changes on the earth; Smith had solidly laid its stratigraphical foundations; and Cuvier was devoting his great talents to the restoration of old higher forms of life. Buckland then commenced his powerful and attractive teaching, and drew around him the younger men, through many of whom his influence on the progress of geology is happily yet felt. In his hands the interesting fauna of the surrounding district was gradually unfolded, and among the most remarkable of the extinct forms then discovered and described by Buckland was the huge Megalosaurus and the small Marsupial,—long the most ancient quadruped known,—of Stonesfield.

But Buckland's great work was that connected with cave remains, in search of which he ransacked England and the Continent, and although the conclusions then enunciated by him, and at that time

very generally accepted by geologists, have not been corroborated, the facts so well recorded and the collections so largely made, remain to attest the value and importance of his labours. It was in connection with these researches that the later discovery of our time,—that of the association of the extinct mammalia with the remains and works of man,—was dimly sighted, but with averted eyes, by my distinguished predecessor. But Buckland did not stand alone; his opinion was shared by geologists of all countries, and it was not until another generation had passed that the evidence so often brought forward, and which had in vain sought examination, respecting the antiquity of man, was confirmed and admitted by geologists.

Such was the aspect of our science at the time this Chair was established, and I propose in this address briefly to notice some of the larger features, whether on questions of theory or on questions of fact, by which its progress has been marked, and which, while they may serve to show how much has been done, will yet indicate how much still remains to be accomplished.

The geologist commences where the astronomer ends. We have to adapt the large and broad generalisations of cosmical phenomena to the minuter details of terrestrial structure and constitution, which

it is our business to study. The common origin of the solar system has been long inferred from the spheroidal figure of the earth and the relations of the planets to one another, and explained by evolution from an original nebulous mass; and geologists have had to consider how far such an hypothesis is in accordance with geological facts. The questions, connected with the earliest stages of the earth's history, are on the very boundary line of our science, but they have too important a bearing on its subsequent stages not to command our serious attention: and though obscure and theoretical they serve to guide us to firmer ground. This nebular hypothesis has recently received from physicists corroboration of a most novel and striking character, equally interesting to geologists and astronomers.

The wonderful discoveries with respect to the solar atmosphere, made by means of the spectroscope, have now presented us with an entirely new class of evidence, which taken in conjunction with the argument derived from figure and plan, gives irresistible weight to the theory of a common origin of the sun and its planets; and while serving to connect our earth with distant worlds, indicates as a corollary what of necessity must have been its early condition and probable constitution.

The whole number of known elements composing the crust and atmosphere of the earth amount only

to sixty-four, and their relative distribution is vastly disproportionate. It has been estimated that Oxygen in combination forms by weight one-half of the earth's crust; Silicon enters for a quarter; then follow Aluminium, Calcium, Magnesium, Potassium, Sodium, Iron, and Carbon. These nine together have been estimated to constitute $\frac{977}{1000}$ of the earth's crust. The other $\frac{23}{1000}$ consist of the remaining fifty-five non-metallic and metallic elements.

The researches of Kirchhoff, Ångström, Thalèn, and Lockyer, have made known, that of these sixty-four terrestrial elements there are twenty present in those parts of the solar atmosphere called the "chromosphere" and "reversing layer," as the stratum which surrounds the photosphere is called from certain optical properties.

They consist of[1]:—

Aluminium.	Chromium.	Lead. (?)	Sodium.
Barium.	Cobalt.	Magnesium.	Strontium.
Cadmium.	Copper. (?)	Manganese.	Titanium.
Calcium.	Hydrogen.	Nickel.	Uranium.
Cerium.	Iron.	Potassium.	Zinc.

[1] On analysing this list we find:—

1 Permanent gas	Hydrogen.		
2 Metals of the Alkalis . .	Sodium.	Potassium.	
All the Metals of the Alkaline Earths	Calcium.	Strontium.	Barium.
3 Metals of the Zinc class .	Magnesium.	Zinc.	Cadmium.

Nor, with possibly two exceptions, does the spectroscope give any indication of unknown elements.

While these phenomena afford such strong additional proofs of the common origin of our solar system, Mr. Norman Lockyer, basing his enquiries upon these and other facts recently acquired on the constitution of the sun, has been led to form some views of singular interest bearing on the probable structure of the crust and nucleus of the earth. With his permission I am enabled to lay before you some of the points in the inquiry he is now pursuing.

Observation and theory have both led him to the unexpected conclusion that in the case of an atmosphere of enormous height and consisting of gases and of metallic elements in a gaseous state, gravity overcomes diffusion, and the various vapours extend to different heights, and so practically arrange themselves in layers; and that in the sun, where owing to the fierce solar temperature the elements exist

All the Metals of the Iron class	Manganese.	Cobalt.	Chromium.
	Iron.	Nickel.	Uranium.
2 Metals of the Tin class . .	Tin.	Titanium.	
1 Metal of the Lead class (probably)	Lead.		

The Metals of the Tungsten, Antimony, Silver, and Gold classes are entirely unrepresented, while, if we accept the metallic nature of hydrogen, there is not a single metalloid on the list, although they have been diligently searched for.

in such a state of vapour and of complete dissociation, the known elements arrange themselves in the main in the following order[2]:—

Coronal Atmosphere . .	Cooler Hydrogen.
Chromosphere	Incandescent Hydrogen. Magnesium. Calcium.
Reversing layer	Sodium. Chromium. Manganese. Iron. Nickel, &c.

Mr. Lockyer suggests, and has communicated some evidence to the Royal Society, in support of his suggestion, that the metalloids or non-metallic ele-

[2] Mr. Lockyer points out that this order is that of the old atomic or combining weights, and not that of the modern atomic weights, as the following table shows :—

	Old Atomic Weights.	New Atomic Weights.
Hydrogen	1	1
Magnesium	12	24
Calcium	20	40
Sodium	23	23
Chromium	26	52·5
Manganese	27	55
Iron	28	56
Nickel	29	58

Aluminium does not find a place in the above list, because its order in the layers has not yet been determined by observation, but the principle referred to would place it between Magnesium and Calcium.

ments as a group lie outside the metallic atmosphere. He also explains why under these conditions their record among the Fraunhofer lines should be a feeble one. Hence he considers that we have no argument against the presence of some quantity of the metalloids in the sun taken as a whole, although that quantity may be small.

Mr. Lockyer then takes the observed facts together with the hypothesis of the external position of the metalloids, and is considering these two questions:—

1. Assuming the earth to have once been in the same condition as the sun now is, what would be the chemical constitution of its crust?

2. Assuming the solar nebula to have once existed as a nebulous star at a temperature of complete dissociation, what would be the chemical constitution of the planets thrown off as the nebulosity contracted?

It will be seen that there is a most intimate connection between these two inquiries. The localisation of the various elements and the reduction of temperature acting in the same way in both cases.

Thus to deal with the first question; as the external gaseous vapours (those of the metalloids) cooled they condensed and fell on the underlying layer where they entered into combination forming one set of binary compounds and then others as

the temperature was reduced, until finally all the metals and earths were precipitated[3].

If now we turn to the earth's crust we find it very generally assumed that the fundamental igneous rocks which underlie the sedimentary strata, and which formed originally the outer layers, may be divided into two great masses, holding a general relation one to the other,—an upper one consisting of Granite and other Plutonic rocks, rich in silica, moderate in alumina, and poor in lime, iron, and magnesia; and of a lower mass of Basaltic and Volcanic rocks of greater specific gravity, with silica in smaller proportions, alumina in equal, and iron, lime, and magnesia in much larger proportions, with also a great variety of other elements as occasional constituents; while the denser metals are in larger proportion in the more central portion of the nucleus. The suggestion of Mr. Lockyer is that this order follows necessarily from the original localisation of the earths and metals before referred to, by which the oxygen, silicon, and other metal-

[3] Firstly, those binary compounds capable of existing at a high temperature, such as the vapour of water, of hydrochloric acid, of silica, carbonic acid, and others would be formed; secondly, the precipitation of these would give rise to numerous reactions, forming a variety of silicates, chlorides, sulphates, &c.; thirdly, with the condensation of water the constitution of minerals would be effected, double decompositions would ensue, and the consolidation of the outer shell commence.

loids formed, as they now do in the sun, an outer atmosphere, succeeded by an inner one consisting in greater part of the alkaline earths and alkalies, then by a lower one of iron and its associated group of metals, and finally by an inner nucleus containing the other and denser metals.

As we have before observed, above nine-tenths of the earth's crust consists of those elements which, on the assumption of the external position of the metalloids, would constitute the outer layers of the nebular mass. Thus oxygen and silicon alone constitute on the average $\frac{75}{100}$ of the mass of acid plutonic rocks of which the upper part of the first assumed shell of the earth consists; beneath it, as a whole, are the basic rocks, into the composition of which calcium, magnesium and iron combined with oxygen enter in the ratio of, say, $\frac{35}{100}$,—while the silicon diminishes in proportion: still deeper lie the denser and harder metals, which reach the surface only through veins transversing the outer layers.

We next come to the second question dealing with the chemical constitution of the planets. It is imagined that the same consideration would hold good, and that the exterior planets may approach in their constitution that of the sun's outer atmosphere, and that the planets may become more metallic as their orbits lie nearer the central portion of the nebula. Mr. Lockyer considers that the

low density and gigantic and highly absorbing atmospheres of the outer planets accords with their being more metalloidal; and that on the other hand the high density and comparatively small and feebly absorbing atmospheres of the inner planets, points to a more intimate relation with the inner layers of the original nebulous mass. For the same reason we should expect to find the metalloids scarcer in the sun than in the earth.

In the Jovian system, and in our own moon, we have a still further support of the hypothesis in the fact that the density of the satellites is less than that of their primary.

I had hoped to have brought before you some of the results of the examination of the spectra of portions of the outer igneous-rock crust of the earth, which Mr. Lockyer kindly undertook to compare with the Solar Spectrum, but owing to the state of the weather, the investigation is not yet complete. It may be stated however that as in the spectrum of the Sun so in the spectra of the Lava, Greenstone and Granite already tested, no trace of the metalloids is present, although Oxygen and Silicon enter so largely into the composition of these rocks.

We can, however, still only look on these views as hypothetical, but they commend themselves to us by their simplicity and grandeur, and their high suggestiveness for future inquiry and research. They

show us also how the spectroscope may, as the microscope has done already, aid the investigations of the geologist,—the one by endowing the eye with new powers of sight with respect to the infinitely minute, and the other with new powers of tangible analysis with respect to the infinitely distant in time and in space.

Quitting the early history of our globe, we leave the domain of the astronomer and enter upon one shared by the geologist, the mineralogist, the chemist, and the mathematician. The elements which we first dealt with in their gaseous and dissociated state have now entered into a multiplicity of combinations giving rise to a vast variety of compound bodies. Instead of the sixty-four simple elements, their mutual reactions have resulted in the formation of somewhere about 1000 varieties of rocks and minerals alone, with which the geologist has in future to deal. He also has to deal with all the physical problems arising from the consolidation of the crust of the earth,—from pressure due to gravitation and contraction,—from the action of subterranean forces,—from the effects of heat,—and with all the varied phenomena resulting from these complex conditions.

Passing for the present over the intermediate stages of consolidation, the continual cooling of the

globe has necessarily resulted in a thickening of its crust, the exact extent of which at the present time has long been the object of geologists to determine.

The inquiry is one of extreme difficulty, and has of late years engaged and is still engaging the attention of some of the ablest physicists and mathematicians. The early belief was that the thickness of the crust of the earth does not now exceed thirty to sixty miles; but the late Mr. Hopkins, reasoning on phenomena connected with precession or nutation, concluded that on the contrary it could not be less than 800 miles thick or more,—a conclusion which has been supported and extended by Sir W. Thompson, who, while maintaining the igneous origin of the globe and the greater intensity of action in past ages, has further proved on dynamical grounds that the earth as a whole must now be more rigid than glass, and probably even more rigid than steel.

It is difficult, however, to reconcile these views with the extent and character of recent volcanic action. This Mr. Robert Mallet endeavours to do in a remarkable paper recently published in the Transactions of the Royal Society. The author bases his views upon Constant Prevost's theory of elevatory forces, but considers that as the secular cooling of the globe has proceeded, and the crust become thicker and more rigid, the tangential pressure, no longer equal to the elevation of moun-

tain ranges, is spent in local crushings of portions of the crust, and that by transformation of the mechanical work of compression, the heat from which terrestrial volcanic agency is at present derived, is produced. Mr. Mallet contends for the high probability that this "crushing of the earth's solid crust affords a supply of energy sufficient to account for terrestrial vulcanicity," comprehending in that term earthquakes and volcanic action. Thus, instead of arising from a deep-seated and common cause, Mr. Mallet would assign present volcanic ejections to the local fusion of the strata at variable but moderate depths beneath the surface; and he considers it characteristic of such action "that it is only one phase of a unique force which has always been in action, though in decreasing energy since our planet was nebulous."

On the other hand, these views have been objected to by other competent observers, who hold with little modification to the original hypothesis of a molten central nucleus and a shell of comparatively small thickness. Such are some of the large physical problems now occupying the attention of geologists. I shall have occasion to recur to them again.

In stratigraphical geology the great divisions originally introduced by our predecessors stand, but their number and the number of sub-divisions have

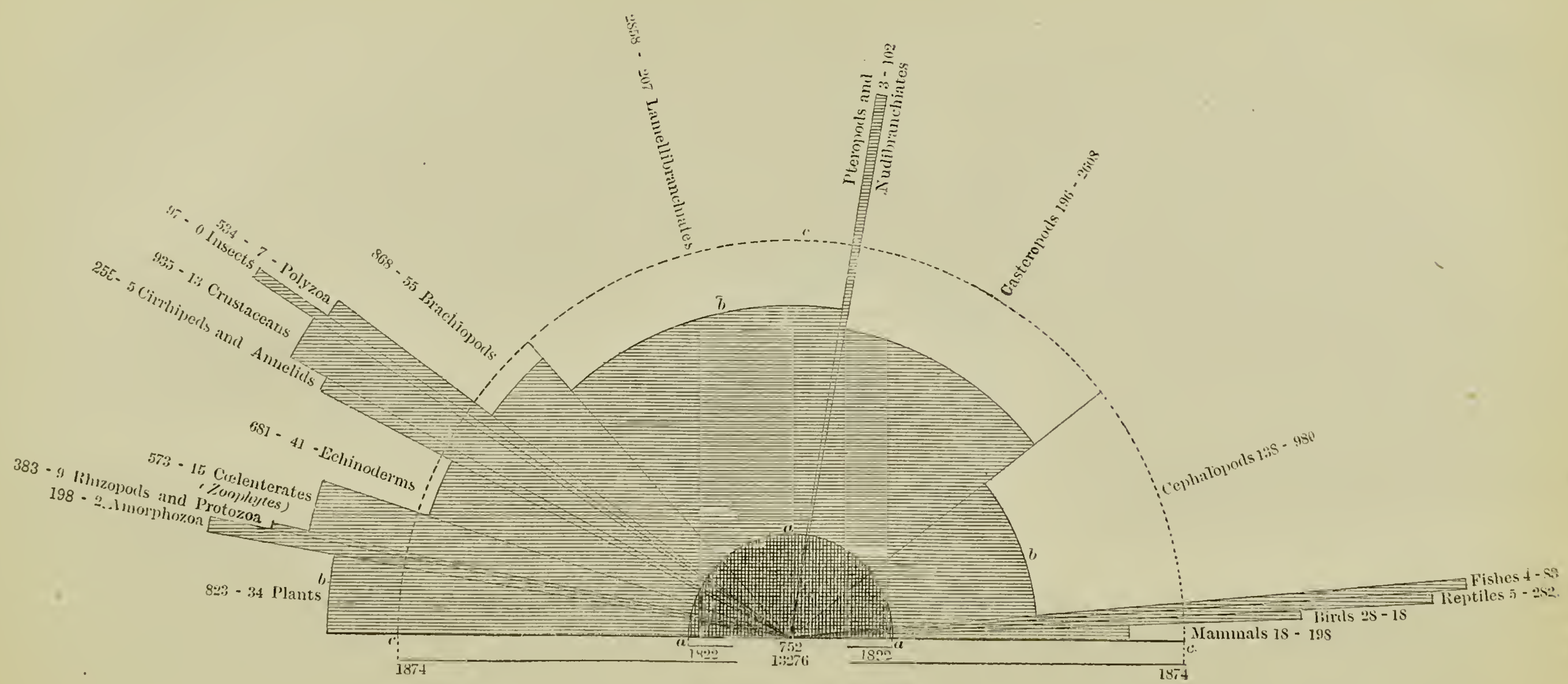
2858 - 207 Lamellibranchiates
Pteropods and Nudibranchiates 3 - 102
Gasteropods 196 - 2608
Cephalopods 138 - 980
868 - 55 Brachiopods
534 - 7 - Polyzoa
97 - 0 Insects
935 - 13 Crustaceans
255 - 5 Cirrhipeds and Annelids
681 - 41 - Echinoderms
573 - 15 Cœlenterates (Zoophytes)
383 - 9 Rhizopods and Protozoa
198 - 2 Amorphozoa
823 - 34 Plants
Fishes 4 - 83
Reptiles 5 - 282
Birds 28 - 18
Mammals 18 - 198
752
13276
1822
1822
1874
1874

FIG. I.

greatly increased. In 1822, when Phillips and Conybeare wrote their "Geology of England and Wales," twenty-three so-called formations were recognised, whereas now thirty-eight such are established, and these are divided into about one hundred and twenty sub-divisions, each characterised by some peculiarity of structure or of fauna. Palæontology as a separate science was not then known; structural and physical geology had chiefly occupied attention; but the study of organic remains has since advanced with such rapid and vigorous strides that the older branch of the subject was until lately in danger of being neglected and distanced.

At that time the number of species of organic remains in Great Britain which had been described amounted only to 752, whereas now the number amounts to the large total of 13,276 species. The relative proportion between these totals and the numbers of each class is exhibited in the annexed diagram, Fig. 1 [4], which shows also the vast pro-

[4] In these diagrams, the inner semi-circle, *a a*, gives the relative proportion between each class in an area which represents the sum of the total; and the outer semi-circle, *c c*, gives the dimensions which each class would have had, had the proportions between the several classes, in each of the two compared periods or stocks, been maintained in the same ratio as in *a a*; whilst the irregular segments, *b*, give approximately the actual increase or excess of each class, showing how comparatively large the additions in some of them have been compared with those in others; and in the case

gress made in palæontological knowledge between 1822[5] and 1874[6].

Some idea of the extent and variety of the past life of our globe may be formed by comparing these figures with the numbers of plants and animals now living in Great Britain. Excluding those classes and families, such as the naked mollusca and others, which from their soft and gelatinous nature decay rapidly and so escape fossilisation, and insects[7]—the preservation of which is exceptional—the number of living species amounts to 3989, against 13,183 extinct species of the same classes, and the relative proportions of each class stands as in the diagram, Fig. 2.

of Fig. 2, showing how particular classes of fossils fall below or exceed in development of their living analogues. The inner numbers attached to the several classes refer to the value of each in the inner circle *a a*, and the outer numbers have reference to the values represented by the segments *b*. The sign × means that certain segments should be so many times larger.

[5] As there was no list of British fossils then published, I have taken the numbers given in Woodward's "Synoptical Table," published in 1830, and deducted from them those added to the stock between 1822 and 1830.

[6] I am indebted to my friend Mr. Etheridge, F. R. S., palæontologist to the Geological Survey, for the particulars of this 1874 stock. The details are given in a valuable Table which he has had the kindness to draw up for me and which is given in full, with the details of the 1822 stock and of living species, in the Appendix.

[7] The number of British species of insects amounts to between 10,000 and 11,000.

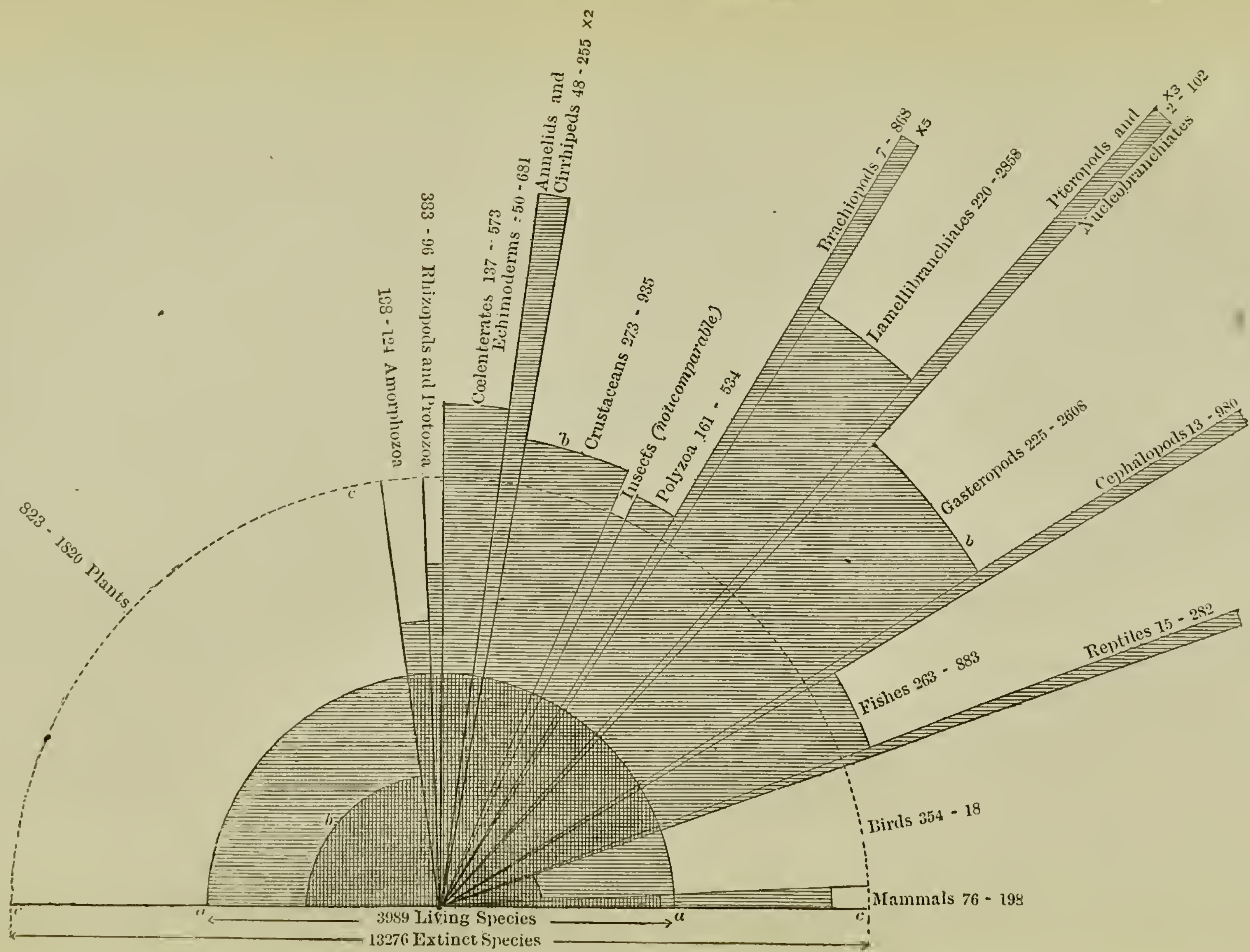
823 - 1820 Plants
138 - 124 Amorphozoa
383 - 96 Rhizopods and Protozoa
Cœlenterates 137 - 573
Echinoderms 50 - 681
Annelids and
Cirrhipeds 48 - 255 x2
Crustaceans 273 - 935
Insects (not comparable)
Polyzoa 161 - 534
Brachiopods 7 - 868 x5
Lamellibranchiates 220 - 2858
Pteropods and
Nucleobranchiates
x3 2 - 102
Gasteropods 225 - 2608
Cephalopods 13 - 980 x9
Reptiles 15 - 282
Fishes 263 - 883
Birds 354 - 18
Mammals 76 - 198
3989 Living Species
13276 Extinct Species

FIG. 2.

Thus while the total number of those classes of vertebrate and invertebrate animals and plants represented in a fossil state, and now living in Great Britain, is only 3989, there formerly lived in the same area as many as 13,276 species, so that the fossil exceed the recent by 9287 species. It must be remembered also that plants are badly represented, for owing to their restricted preservation, the fossil species only number 823 against 1820 recent species. Birds are still worse represented, as only 18 fossil species occur against 354 recent species.

But the multiplicity of British fossils, however surprising as a whole, has to be viewed in another and different light. The large total represents, not as the recent species do, the life of one period, but the sum of those of all the geological periods. Geological periods, as we construct them, are necessarily arbitrary. The whole geological series consists of sub-divisions, each one of which is marked by a certain number of characteristic species, but each having a large proportion of species common to the sub-divisions above and below it. These various sub-divisions are again massed into groups or stages, having certain features and certain species peculiar to them and common throughout, and which groups are separated from the groups above and below by greater breaks in the continuity of life and of stratification than mark the lesser

divisions. As these on the whole severally exhibit a distinct fauna and flora, we may conveniently consider them as periods, each having its own distinctive life, and the number of which in Great Britain we have taken approximatively at thirty-eight.

The number of species common to one period and another varies very greatly, but taking the average of the sixteen divisions of the Jurassic and Cretaceous series, of which the lists were, with a portion of those of the older series, given a few years since by Professor Ramsay[8], we may assume that about thirty per cent. of the organic remains pass from one stage to another. Dividing the 13,276 fossil species among the thirty-eight stages, or omitting the lower stages and some others and taking only thirty, we get a rough average of 442 species for each; and, allowing in addition for the number common to every two periods, we obtain a mean of 630 species as the population of each of the thirty periods against the 3989 species of the present period. On this view the relative numbers are therefore reversed, as shown in the annexed diagram, Fig. 3, where the number of living British species is compared with the mean of the extinct species assumed for any one past period of the same area.

This gives a ratio for the fauna or flora of a past

[8] Anniversary Addresses for 1863 and 1864, Quarterly Journal Geological Society. The tables were computed by Mr. Etheridge.

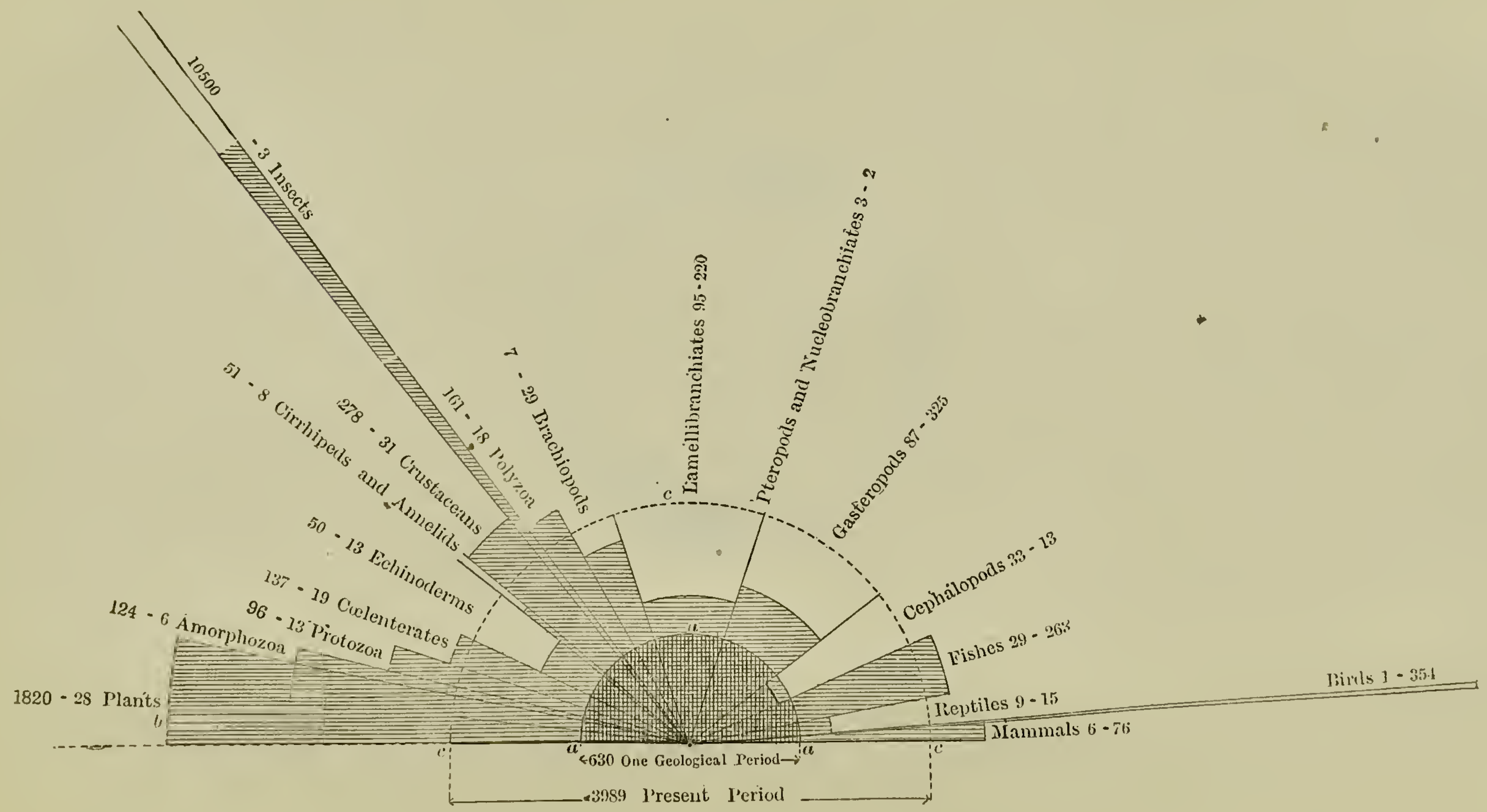
10500
- 3 Insects
161 - 18 Polyzoa
7 - 29 Brachiopods
278 - 31 Crustaceans
51 - 8 Cirrhipeds and Annelids
50 - 13 Echinoderms
137 - 19 Cœlenterates
96 - 13 Protozoa
124 - 6 Amorphozoa
1820 - 28 Plants
b
c
Lamellibranchiates 95 - 220
Pteropods and Nucleobranchiates 3 - 2
Gasteropods 87 - 325
Cephalopods 33 - 13
Fishes 29 - 263
Birds 1 - 354
Reptiles 9 - 15
Mammals 6 - 76
a
a
c
c
630 One Geological Period
3989 Present Period

FIG. 3.

to that of the present period of only as 1 : $6\frac{1}{3}$. But it must be remembered that probably the actual as well as the relative numbers of the several classes *inter se* in each and all of these several formations, varied greatly at the different geological periods. Still we have no reason to suppose but that during the greater part of them life of one form or another was as prolific, or nearly so, in the British area then as at the present day, and we may thus form some conception of how little relatively, though so much really, we have yet discovered, and of how much yet remains to be done, before we can re-establish the old lands and seas of each successive period, with their full and significant populations. This we cannot hope ever to succeed in accomplishing fully, for decay has been too quick and the rock entombment too much out of our reach ever to yield up all the varieties of past life ; but although the limits of the horizon may never be reached, the field may be vastly extended ; each segment of that semi-circle may yet be prolonged we know not how far : and it is in this extension —in the filling up of the blanks existing in the life of each particular period—that lies one great work of the future. The field which thus embraces the study of all the varied forms of life in all past time, has now, as we have just shown, attained such vast dimensions, as will require for its due and continued

cultivation the active and unceasing co-operation of geologists and palæontologists.

We now come to the more especial ground of the geologist. Starting with investigations connected with the origin of the globe, he has to trace the changes it has undergone through the various phases of its history, to determine the cause of those changes, and the manner in which they were effected. Besides investigating the character and distribution of all organised things inhabiting the earth in all former periods,—their order of succession, and the relation of the several and successive groups one to another,—he has also to study various chemical and physical questions connected with inorganic matter.

In the infancy of the science geologists generally sought to explain the great mechanical phenomena exhibited on the surface of the globe by energy rather than by length of action. The philosophy of Hutton, Playfair, and their successors, checked this disposition, and has led to more temperate methods of explanation; but it is a question whether the licence which formerly was taken with energy is not now too much taken with time. Small forces long continued, action frequently repeated, and maintained uniformity of operation, are accepted as sufficient to account for the formation of our hills and plains, of

the Alps and the Andes, and for all the great general as well as special features of the earth's crust.

I am aware that in expressing other views I shall have occasion to differ from men for whose opinion I have the highest regard, and who have done infinite service to the progress of scientific geology; but I am also expressing views which I was very early led to form, and which long experience has only tended to confirm. The points at issue are, firstly, whether our experience on these questions is sufficient to enable us to reason from analogy; and secondly, whether all former changes of the earth's surface are to be explained by the agency of forces alike in *kind* and *degree* with those now in action. It is not possible in the limits of this address to do full justice to these important questions. I may, however, briefly state my reasons for answering these questions in the negative.

The value of experience with respect to natural phenomena depends upon whether they are symmetrical and not variable, or whether they are variable and unsymmetrical. In the one case, as any one part bears a given uniform relation to the whole, if one part be known, the whole can be inferred; but in the other case, where the whole is made up of unequal and not uniform parts, the value of the evidence is merely in proportion to the number of those parts independently determined, or to

the ratio between the duration of the observation and the duration of the time comprising all the phases of the particular phenomenon. Thus the path of a planet, the date of an eclipse, or the return of a comet, may be predicted with certainty by the determination of mere minute sections of their orbits, which in respect to time are infinitely small compared to the length of the cycle of revolution. On the other hand the metamorphosis of an insect, the mean temperature of a place, or the character of a volcano, can only be accurately determined by a length of observation sufficient to embrace all the variations they respectively present in their several cycles of change. In the case of the insect the time must be equal to the duration of the metamorphosis; in that of temperature a succession of years is needed to obtain a mean; and, with respect to volcanoes, centuries may often pass before we become acquainted with all the irregular exhibitions of their spasmodic activity.

The necessity for a much greater extension of time becomes yet more imperative when we come to deal with geological phenomena, such as those due to the action of elevatory forces, which are extremely varied in their nature,—being at one time exhibited by a raised beach, a few feet high, and at another by a mountain chain, whose height is measured by miles; or by the small displacement

produced by an earthquake, and the rectilinear fracture of a county with a displacement of thousands of feet.

In taking into consideration the weight of the evidence where the series is so variable and irregular, it is clear that the increment of value is in proportion to the increment of time. One phase of the insect life, one year's record of temperature, a century's observation of the volcano, give evidence which, although of value 'pro tanto,' as one link in the chain, is entirely inconclusive when applied to the whole length. So in respect to such geological changes as those just named, the value of our experience is only in the proportion of the length thereof to the duration or cycle of the phenomenon under investigation. Thus the elevation of mountain ranges have been events of rare and distant occurrence. Supposing, as has been estimated, that all the great chains can be referred to thirteen principal epochs; or, taking subordinate ranges, that the elevation of the mountain chains of the old world be limited to twenty such periods. Divide geological time (since the sufficient consolidation of the crust of the earth) by this or even by double this number, and we may form some conception of the length of the cycles involving changes of this magnitude. What that time is it is impossible to say; we can only

feel how infinitely it exceeds all our limited experience. With respect thereto the experience of five hundred years is no doubt of value,—one or two thousand years add further to it;—but after all how insignificant that duration of time is compared to the time over which the cycle extends; it may be as 1 : 100, or it may be as 1 : 200 or more, and I shall show further on (p. 47) that there are circumstances which indefinitely extend even these proportions. I conclude, therefore, that our experience in these cases is by far too limited to furnish us with reliable data; and that any attempt to reason solely from part to the whole must prove fallacious. Another argument adduced in support of this theory is, in my opinion, equally untenable.

It is asserted that taking the degree of elevatory force now in operation, and allowing quantity of time, the repetition of the small changes on the surface witnessed by us would produce, in time, results of any known magnitude, i. e. that the force which could elevate a district 5 feet in a century would suffice in 100,000 years to raise it 5000 feet. This reasoning might be conclusive, if we had cause to suppose that the force were uniform and constant, but even our limited experience shows this to be irregular and paroxysmal; and although the effects indicate the nature of the force, they in no way give us a measure of its degree.

Before I proceed further I must remove two objections which have been urged against what has been called the cataclysmic theory in opposition to the uniformitarian theory,—both terms in themselves inaccurate from their exaggeration, as all such terms usually are. One is that we require forces other than those which we see in operation, and the other that it is unnecessarily sought to do by violent means that which can be equally well effected by time. It is not however a question raised as to the nature of the force, but as to its energy; it is not a question of necessity one way or the other, but of interpretation: it is a question of dynamics and not of time, and we cannot accept the introduction of time in explanation of problems the real difficulties of which are thereby more often passed over than solved. Time may and must be used as without limits: there is no reason why any attempt should be made either to extend or to curtail it; but while there is no need for frugality, there is no wisdom in prodigality. After all it will be found that, whichever theory is adopted, the need will not be very different; the mountain range, for the gradual elevation of which the one will ask 100,000 years, the other may require for its more sudden elevation a force taking the same number of years to accumulate its energies.

We must, however, judge of the past by the features it has stamped on the land[9], and these we must interpret not entirely by our own experience, not alone by our estimate of force, but by our knowledge of what amount of force the energy due to the thermal condition of the globe can develope on known dynamical principles, and by our observation of what those forces have effected in past times.

However we may differ in our interpretation of the present thermal state of the globe, most geologists agree in accepting the hypothesis of central heat as the one best in accordance with known facts relating to subterranean temperature, the eruption of igneous rocks, the action of metamorphism, and the crushing and contortions of rock masses. The radiation of heat into space has been accompanied by a gradual contraction of the central mass, and a shrinking of the crust, to which the trough of oceans, the elevation of continents, the protrusion of mountain chains, and the faulting of strata are to be attributed. The question is whether that contraction was accompanied by a like gradual yielding and adaptation of the solid

[9] The evidence of facts with respect to the glacial period has led to the admission of a greater intensity of cold: so we contend that the evidence of the past, at times, respecting the greater effects of heat is equally definite.

crust to the lessening circumference of the globe; or whether the resistance of the rigid crust was only overcome by paroxysmal efforts. This latter was the view held by most of our early geologists, and is still the prevailing one abroad.

It is not necessary here to deal with the first steps of the problem. Let us take it after, for example, the readjustment of the crust (when it must have been many miles thick) which resulted in the elevation of such a mountain chain as that of the Alps; and here I must assume a point in advance. The resisting strata having given way to the tension to which they had been subjected, a state of equilibrium and repose would for a time ensue. As the secular refrigeration subsequently proceeded, the tangential force due to contraction resumed action, and while certain larger areas were depressed, chiefly by the action of gravity, other and smaller portions of the crust presenting less resistance yielded, and rose at right angles to the tangential pressure.

Now either, if the elevatory force were limited and uniform in degree, a point would be reached at which that force was balanced by the increasing resistance and weight of the strata, and the movement would cease; or else, if the energy was a constantly generated quantity, and the rigidity such as to prevent yielding beyond a certain extent (and no

solid crust can be perfectly flexible), then it would be a dynamical necessity that a time would come when, from the accumulation of that energy, it would overcome the resistance, and the opposing strata be suddenly rent and fractured. This primary resistance removed, the full power of the elevatory force would be brought to bear upon the disjointed mass, and the surplus energy expended in at once rapidly forcing forward and tilting up the now yielding strata, along the line of fracture, to that position and that height required to restore a state of equilibrium, and no more. It is not possible for any number of minor forces, where the ultimate resistance exceeds each one taken separately, to accomplish in any time, however long, that which requires for its execution a major force of infinitely greater power.

Either a minor force, if sufficient to move a given weight, will go on moving, or else, if from any cause a further or secondary and independent resistance, such as in this case that dependent on the cohesion of the strata, has to be met, additional power must be brought to bear, which, if that secondary resistance be then overcome, the cumulated force being far in excess of the residual resistance will be immediately expended with energy in proportion to the magnitude of the resistance mastered. Thus, although a railway engine could readily move ten carriages,

it could not move one hundred. It is true that if it were allowed to proceed with ten carriages at a time it could perform the removal of the whole in ten journeys, but if that were not practicable, it would require the simultaneous application, say of ten engines, to accomplish the same journey at one time, and by no other means could the inertia of the mass be overcome; although when once overcome the force employed would be largely in excess of that required for traction only.

Again, in the case of large faults traversing thick masses of strata the conditions are nearly the same. For example, in the great Craven fault which brings the disjointed edges of the Silurian Rocks on a level with the disjointed edges of the Coal Measures, the extent of displacement is in places as much as 4000 feet, and the range of the fault exceeds fifty miles. If we take the thickness of the strata so fractured at 20,000, or any greater number of feet, it is not possible to conceive any small force acting through any length of time to have effected their disruption, unless it could be imagined that the fault had proceeded progressively with the gradual accumulation of the strata, which is impossible. In any way, the fracture must have occurred suddenly at the moment the tension overcame the resistance of the mass; it then necessarily follows that with the residual resistance reduced

to mere gravity, a displacement, ending in a state of equilibrium of the fractured strata, would at once ensue, the amount of displacement being in proportion to the severity of the strain.

The results of the foregoing conditions are in perfect accordance with observation. The enormous crumpling and folding of the strata — the vast upthrow of their disjointed edges—indicate the resistless forces which have been at work, have been spent, and again repeated. Of these forces, it is as difficult for us to realise the intensity as it is to fathom the immensity of space. These are among the questions for the future.

While thus refrigeration progressed and the shell of the globe became thicker, other causes came into operation to give it greater rigidity, and so better fit it for the habitation of man.

In the many discussions to which this question has given rise, it has been too much assumed that the shell was of uniform or nearly uniform thickness; the irregularities of the upper surface were apparent, but those possible on the under surface have been scarcely sufficiently considered. I have however reason to suppose, from some collateral researches, that the under surface of the shell is ribbed and channelled in a manner and on a scale materially to influence the operation of that fluidity

of the nucleus and mobility of the crust on which so many able and elaborate calculations have been based.

Let us take on a continental area, having a mean surface temperature of 55° Fahr., a point in the earth's crust through which any isotherm of depth

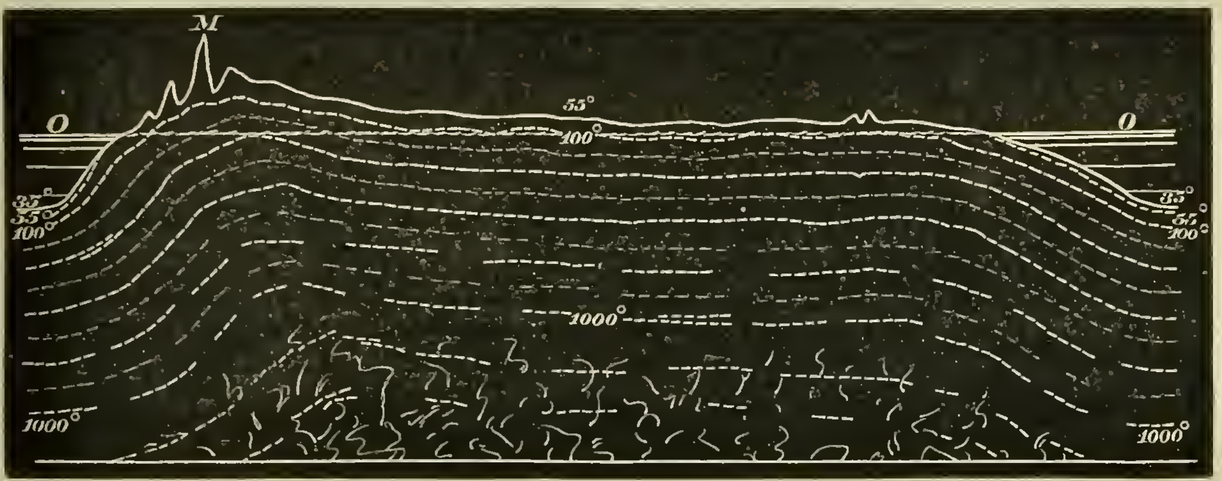

Fig. 4.

passes,—suppose it be that of 1000°. This earth-isotherm will possibly be found at a depth of between 50,000 and 100,000 feet[10]. The isothermal plane must approximatively follow the contours of the surface, and in mountain districts, M, may rise some 1000 to 4000 feet above its other level. But when we come to seas such as the Mediterranean, the sea-bed has the mean temperature of the surface (or more cor-

[10] There is reason to believe that the rate of increase of temperature of 1° F. for every 50 to 60 feet of depth, which obtains near the surface, is, owing to the increased conductive power of the rocks, very much less at greater depths.

rectly the mean temperature of the winter months), and the depth of that bed being from 6000 to 8000 feet, the earth's thermal plane of 1000° is thrown proportionally lower than on the adjacent land.

With the great oceans, O, other conditions come into operation which increase the difference, for the cold Arctic waters pass in an undercurrent from the poles to the Equator with so little loss of heat, that near the Equator a deep-sea temperature of 35° F. or even lower exists. Therefore to the depth of the ocean we have to add a depth equivalent to the difference between the mean temperature of the adjacent land and that of the deep waters. In the Arctic zone the temperature of the land is less than that of the sea, but as we approach the Equator the former exceeds that of the latter at depths by as much as 40°, which is equal to a difference in depth of about 2000 feet. The main channels of the great oceanic troughs in the tropics have a depth of 18,000 feet or more. If we add to this 2000 feet for the difference of temperature between the surface and the sea-bed, and 4000 feet for the rise under certain mountain chains, we shall have a total of 24,000 feet as the approximate difference of level of the isotherm of 1000° in adjacent continental and oceanic areas [11].

As the position of the other earth-isotherms

[11] The numbers used are merely approximative.

will in like manner occupy successive planes approximatively parallel with the surface whether of land or sea-bed, it follows that, if a central molten nucleus exists, it will be divided into areas separated by boundary lines no less important than those formed by the continental areas between the several oceanic areas on the surface; and, as they are even more enclosed and isolated, their condition with regard to the possible existence of tidal action would approach more to that of an inland sea such as the Mediterranean, where their influence is scarcely felt. It may be a question also whether the rigidity of the earth's crust is not influenced by this mode of structure. It must certainly affect the permanence of continental and oceanic areas.

Notwithstanding this it may naturally be asked, in view of the more constant slow changes and movements to which in past times the crust of the earth has been subject—and that even up to a period so geologically recent as the elevation of the Alps and the Andes,—how it happens that it is now so quiescent and comparatively immovable. The hypotheses both of Mr. Hopkins and Sir W. Thompson grapple with this difficulty. The former not only considered that the crust was 800 to 1000 miles thick, but he also supposed that there were only local and limited bodies of molten matter,

the rest of the nucleus having become solid. The latter also concludes, though on other grounds, that the secular refrigeration, combined with the excessive pressure, has led to a solidification, commencing at the centre, of the whole interior of our globe [12]; and as before mentioned, Mr. Mallet, admitting the principle of a solid crust of great thickness, has proposed a theory to account for the continued ejection of molten matter from depths not far beneath the surface, and acting independently of any common source of lava supply, by the conversion of the energy resulting from crushing into heat along given lines of intense pressure.

It seems however to me that the uniform character appertaining to volcanic eruptions over the whole world, the travelling of earthquake movements, the flexibility yet evinced in movements of the crust, and the magnitude of the later geo-

[11] The Rev. Osmond Fisher, on the other hand, showed in 1873 (Geological Magazine, vol. x. p. 248) that on the supposition of a globe becoming solid throughout at the melting temperature, and afterwards cooling as a solid, the amount of crumplings and contortions of the surface which could be produced by its subsequent refrigeration, would be very much smaller than sufficient to account for the existing inequalities of the earth's surface; and hence he concluded that such has not been the mode in which the earth has attained its present state, but that a crust commenced to form before the interior became solid. (See also Mr. Fisher's paper 'On the Elevation of Mountain Chains' in Trans. Cambridge Phil. Soc. for 1869, vol xi. part iii.)

logical changes, precludes the acceptance of the conditions suggested by these distinguished physicists, and leads me to seek for other causes to account for the present stable condition of the earth.

The cause which suggests itself to me is the intense cold of the glacial period through which the earth has so recently passed, and which has, as it were, anticipated or forestalled the refrigeration which, in ordinary course, would have taken a longer time, and so extended into some subsequent period. At present the annual variation of temperature in these latitudes extends to a depth of about 30 feet; the maximum heat of summer being felt underground by the end of November, and the maximum cold of winter by the beginning of June, at a depth of 26 feet. But supposing the cold of winter at depths not to be influenced by summer heat, then the abstraction of heat would continue to a depth in proportion to the length of time during which the cold at the surface was maintained; and such would be the effect over a large portion of the northern hemisphere (and I believe of the southern contemporaneously) during the glacial period. For as permanent ice and snow then extended down to these latitudes, the summer sun would not sensibly affect surfaces so covered, and the abstraction of heat must have proceeded uninterruptedly. To what depth the effect may have extended has not yet

been investigated, but that it must have been very considerable is evident from the depth to which the annual variations are now felt. Consequently, with an uniform permanent temperature of 32°, or lower, at the surface, and with the long duration of the glacial period, we may form some conception of how far beneath the surface the extreme cold must have extended; even now, in parts of Siberia, the ground is permanently frozen to a depth of 300 to 400 feet. Then the surface temperature in these latitudes, instead of commencing as now with a mean of 50°, and attaining a degree, say of 70°, at a depth of 1000 feet, commenced with a temperature of 32° F. or less, and the isothermal of 70° must have been proportionately depressed very far below its present level. On the return of the present more temperate climate, that portion of the crust of the earth, measuring certainly many hundreds, and possibly some thousands of feet in depth, which had suffered from this abnormal loss of heat, would have to recover its equilibrium with existing conditions by another change in the isothermal planes, and, until that was effected, little or no loss by radiation would take place.

Or to look at it in another way, let us suppose periods of equal temperature before and after the glacial epoch. As the radiation of heat is in proportion to the difference of temperature between

the warm body and the surrounding medium, the loss of heat by the earth would, if no colder period had intervened, have been nearly equal in equal times; but with the greater cold of the glacial epoch, the same result would be effected in a shorter time, or what is tantamount, the loss in the same time during the glacial period would be greater than in the other two periods. Thus supposing we take any given time of the glacial period as producing a refrigeration of the crust equal to that which would be effected in a certain longer time of the pre-glacial or post-glacial periods, then for a term of time, of length having a certain relation to the difference between the two, succeeding the glacial epoch the earth would, with its outer crust so much below the normal, lose little or no heat by radiation, so that during that subsequent period the thermo-dynamical effects due to cooling would be reduced to a minimum or cease altogether, and a period of nearly stable equilibrium, such as now prevails, obtain.

This last great change in the long geological record is one of so exceptional a nature, that, as I have formerly elsewhere observed[13], it deeply impresses me with the belief of great purpose and all-wise design, in staying that progressive refrigeration and contraction on which the movements of the crust of

[12] Philosophical Transactions for 1864, p. 305.

the earth depend, and which has thus had imparted to it that rigidity and stability which now render it so fit and suitable for the habitation of civilised man: for, without that immobility, the slow and constantly recurring changes would, apart from the rarer and greater catastrophes, have rendered our rivers unnavigable, our harbours inaccessible, our edifices insecure, our springs ever-varying, and our climates ever-changing; and, while some districts would have been gradually uplifted, other whole countries must have been gradually submerged; and against this inevitable destiny no human foresight could have prevailed.

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BY E. P. HALL AND J. H. STACY
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Table showing the number and distribution of the fossil Fauna and fossil, by Mr. R. Etheridge; with which is compared the number

Period.	Plantæ.	Amorphozoa.	Protozoa Rhizopoda.	Cœlenterata.	Echinodermata.	Annelida.	Cirrhipedia.	Crustacea.
Present	1820 *a*	124	96	137 *b*	50 *c*	21 *d*	27	278 *e*
1. Tertiary	224	2	160	66	47	37	24	123
2. Cretaceous . . .	27	144	137	67	192	40	25	80
3. Purbeck and Wealden .	38	0	0	0	1	1	0	11
4. Lias and Oolite . .	160	10	42	163	194	37	7	45
5. Rhætic	1	0	0	7	0	0	1	3
6. Trias	10	0	27	0	0	0	0	0
7. Permian . . .	20	5	7	5	2	5	0	28
8. Carboniferous . .	320	3	10	125	132	23	0	195
9. Devonian . . .	6	9	0	53	21	2	0	17
10. Old Red Sandstone .	13	0	0	0	0	1	2	22
11. Silurian . . .	4	21	0	87	90	36	2	307
12. Cambrian † . . .	0	4	0	0	2	12	0	104
Total in 1874 . .	823	198	383	573	681	194	61	935
Total in 1822 . .	34	2	9	15	41	3	2	13
Living species found fossil in Britain . .	10 ?	2	56	0	5	6	10	17

* Or excluding Birds, 3635.

** The number of insects now known amounts to between 10,000 and 11,000 species.

† From the Longmynd to the Tremadoc rocks inclusive.

DIX.

...a of Great Britain in 1874, *and of the species now living and found ...ecent species and of the fossil species known in* 1822. (See p. 22.)

Polyzoa.	Brachiopoda.	Monomyria.	Dimyaria.	Pteropoda and Nucleobranchiata.	Gasteropoda.	Cephalopoda.	Pisces.	Reptilia.	Aves.	Mammalia.	TOTALS.
161	7	27	193	2	325 *f*	13	263	15	354	76	3989*
150	12	93	635	1	1180	13	123	43	16	160	3109
100	107	197	237	0	207	0	96	50	2	0	1943
0	0	9	36	0	34	0	37	43	0	30	300
60	185	350	685	0	823	435	191	89	0	5	3506
0	1	13	25	0	16	0	28	3	0	3	103
0	0	0	0	0	0	0	4	18	0	0	59
6	22	9	27	1	26	1	22	17	0	0	203
64	160	143	196	30	174	145	240	19	0	0	1989
13	100	22	36	10	46	52	4	0	0	0	391
0	0	0	1	0	0	0	126	0	0	0	165
140	263	30	102	40	102	97	12	0	0	0	1333
1	18	0	12	20	0	2	0	0	0	0	175
534	868	866	1992	102	2608	980	883	282	18	198	13276
7	55	207	207	3	196	138	4	5	0	18	752
39	4	21	160	1	306	0	0	0	2 ?	26	665

a, omitting 597 Mosses, 2816 Fungi, 660 Algæ, etc.
b, excluding 175 Actiniæ,
c, ,, 23 Holothuridæ, etc.
d, ,, 206 Soft-bodied Annelidæ,
e, ,, 63 Internal Parasites,
f, ,, 111 Nudibranchiata,

(*b*–*f*:) Species whose remains as a rule do not admit of fossilisation.

p 41 : foot note : $\frac{dW}{dx}$